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PHYSIOLOGICAL AND HYGIENIC EVALUATION OF THE LIFE SUPPORT SYSTEMS USED ON VOSTOK AND VOSKHOD SPACECRAFT

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ABSTRACT

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The life support systems for the Vostok and Voskhod spacecraft were developed within the design limitations of the craft to cover normal flight and some emergency situations. Extensive ground research went into the design of these systems, which are not self-regenerating but are based on chemically-bound oxygen, CO_2 and water vapor absorbents, and carried food and water stocks. Various life support schemes and their suitability under different flight conditions are discussed. Data from ground studies of life support systems are presented and compared with data from actual Vostok and Voskhod flights.

Author

The physiological and hygienic requirements for the life support systems /1* of Vostok and Voskhod spacecraft were formulated in the course of designing the vehicles and revised in laboratory and pre-flight trials. The establishment of basic parameters for the artificial atmosphere and the selection of a basic scheme for the life support system were both accomplished with an eye to projected flight conditions and possible emergency situations.

The flights of the first Vostok vehicles were planned to include a relatively brief orbital flight phase, but even so the possibility that vehicles

*Numbers given in the margin indicate the pagination in the original foreign text.

of the same design might also be used for longer flights was kept in mind. The possibility of emergency situations in which flight might be prolonged up to 7 to 12 days, with a gradual rise in the temperature of air in the cabin enclosure to +35°C, was also anticipated.

Moreover, the possibility of the failure of cabin pressurization in flight or sudden loss of barometric pressure in case of emergency ejection of the cosmonaut during insertion of the vehicle into orbit was not forgotten.

For these reasons, the air regeneration and air conditioning systems and food and water supplies to be carried on board were planned to sustain a single cosmonaut for a 12-day flight in a pressurized cabin. A pressurized safety suit was to be used in case of failure of cabin pressurization, for long enough to select a favorable site and land the vehicle. /2

The development of life support systems first of all requires that the average daily, minimum, and maximum energy expenditures of a human under conditions of spaceflight be established, in order that gas metabolism values and human food requirements can be determined in their turn.

Since at the time when the life support system was being developed for the Vostok vehicle no experimental materials were available on the combined effect of spaceflight factors on human energy expenditure and gas metabolism, it was necessary to use indirect data obtained by duplicating the nature and scope of proposed cosmonaut activity under laboratory conditions simulating a sojourn in a spacecraft cabin.

To this end, 15 experiments were conducted with subjects in sealed cabins imitating activity appropriate to the various stages of spaceflight. The subjects chosen were healthy young men weighing 65 to 72 kg and 166 to 173 cm tall. The experiments ran from 1 to 15 days in length.

In 7 of the experiments the subjects were in hermetically-sealed Vostok cabin mockups wearing suits ventilated with 50 to 200 liters of cabin air per minute. The temperature of the air and cabin enclosure in 10 experiments was /3 maintained at 20 ± 2°C. In 5 experiments lasting 12 to 13 days the air temperature was gradually increased to 35°C. Gas metabolism, energy expenditure, and moisture loss studies in all the experiments were based on the results of analysis of regenerated matter and drying agents, and a number of the experiments were backed up by the measurements of Douglas-Holden. In addition, special experiments were conducted in which the energy losses of the subject and the entire complex of cabin equipment were determined by direct calorimetry.

The investigations conducted yielded the following data:

average daily O_2 requirement, 480 to 530 liters

average daily CO_2 excretion, 390 to 430 liters

average daily moisture loss, 980 to 1120 grams (for an air temperature of 15° to 22°C)

average daily heat production, 2310 to 2550 kcal

maximum energy expenditure (waking), 228 kcal/hr

minimum energy expenditure (sleeping), 70 kcal/hr

Gas metabolism and heat expenditure studies of Cosmonauts Yu. A. Gagarin, G. S. Titov, and others, conducted in spacecraft cabin mockups, yielded analogous results.

Naturally, the above enumerated experiments did not attempt to reproduce weightlessness or the emotional tension experienced by the cosmonauts owing to the unfamiliarity of the conditions on the first flights. Nonetheless, it was possible to use the figures obtained as guidelines for the basic calculation of life support systems, while providing appropriate reserves to take

care of unforeseen contingencies. In addition, the first brief spaceflights were bound to provide known corrections for the calculated values.

Work on the development of a food ration was carried on concurrently with /4 the experimental determination of gas metabolism and energy expenditure. The basic biochemical metabolic indices of the experimental subjects and cosmonauts were studied under conditions imitating spaceflight. This led to the discovery of some increase in protein and vitamin requirements of the organism, which was taken into account in making up the ration.

The food ration used on the Vostok vehicles was made up of two parts. The first was designed for flights of normal (projected) duration; it had a calorie count of 2500 to 2700 kcal/24 hrs and averaged 120 g/24hrs of protein, 85 g/24 hrs of fats, and 300 g/24 hrs of carbohydrates. The second part of the ration was designed for use in emergency situations in which the flight might be prolonged. The emergency reserve ration contained 1450 kcal/24 hrs.

The makeup of the food ration underwent some modifications from flight to flight, which mainly consisted of the replacement of the puree-type preserves which had been the principal component of meals on the Vostok-1 and Vostok-2 with natural products on all later flights.

The water supply system was based on a total water requirement (including water contained in the food ration) of 2200 g/24hrs, which under laboratory condtions had considerably exceeded the amount required to maintain the water balance of the experimental subjects and cosmonauts.

The air regeneration and conditioning system for the Vostok and Voskhod vehicles was based on stored oxygen and absorbents capable of collecting water vapor and carbon dioxide even at low partial pressures. A part of the /5

moisture was removed from the cabin air by condensation on the surface of the heat exchanger. Oxygen was stored in chemically-bound form in peroxides of alkali metals. The use of chemically-bound oxygen was justified by its combination of a high degree of system reliability with relatively good weight characteristics. When they absorb moisture, the peroxides liberate oxygen, and the alkali thus formed absorbs carbon dioxide. Silica gel impregnated with lithium chloride and activated charcoal were used as supplementary drying agents. The other gaseous products of metabolism were broken down or absorbed by regenerating substances or special filters.

The rate of ventilation through the regeneration system was designed to keep the carbon dioxide concentration at a level of 0.5 to 1.0%, assuming a CO_2 excretion of one cosmonaut of up to 20 liters/hour. Taking into account the decreased absorption capacity of the absorbent as it is used up, the ventilation rate was established at 50 liters/minute for the Vostok ships and 180 liters/minute for Voskhod.

Since the air conditioning systems used on the Vostok and Voskhod vehicles are practically identical, their design and working principle can be given in a single schematic diagram (fig. 1). The system consisted of four main functional elements:

1) A unit for automatic maintenance of the required gas composition of the cabin atmosphere;

2) A unit for automatic maintenance of cabin air humidity at a set level;

3) A unit for automatic maintenance of the required temperature conditions; and /6

4) A unit for monitoring the basic parameters of the cabin atmosphere.

The unit for automatic maintenance of the required gas composition of the pressurized cabin atmosphere consisted of the following components:

1) 2 fans with electric motors (1)*

2) a regenerator with a regulating device (2, 3, 4)

3) a dust filter and a filter for noxious substances (0)

To assure the passage of a continuous stream of air through the regenerating unit, two fans with electric motors were used in the system. The use of two fans considerably increased system reliability. In case of failure of the main fan, the reserve fan was switched on automatically.

An air guide assured the passage of the air stream from the fan through all parts of the regeneration system.

The regenerator and regulator were combined into a single unit. The regenerator consisted of a metal container of the regenerating substance with an oxygen supply sufficient for the entire planned flight period. A filter was placed at the regenerator unit outlet. The regulating device intended to assure maintenance of a given oxygen content in the cabin atmosphere consisted of a distributing valve with a sensitive element reacting to in the partial oxygen pressure in the cabin.

Since the limits of permissible variation for the partial oxygen pressure in air for respiration are rather broad, there was no rigid require- /7 ment for the regulating device to narrow the amplitude of oxygen concentration variation. This permitted the design of this device to be greatly simplified and the reliability of both the regulator, and the system as a whole, to be considerably increased.

Since the operation of the regenerating unit removed only a part of the moisture excreted in the course of human vital activity, the system was pro-

*Numbers refer to fig. 1.

vided with a supplementary drying unit for removal of excess moisture, which was designed to maintain a preset humidity in the air of the pressurized cabin. This drying unit consisted of the following components:

1) 2 cartridges filled with absorbent material (5, 6)*
2) an automatic valve (9)
3) 2 manually operated valves (7, 8)
4) a device for collecting condensate from the heat exchanger (10)
5) a hygrometer (16)

The first cartridge, with a calibrated opening, is incorporated into the collector funnel of the fan system. A constant amount of air passes through this dryer, which is in operation all the time the whole system is switched on.

The second cartridge of the drying system is connected by an air hose to the collector funnel of the air regeneration system. The automatic and manually operated valves control flow through this hose. Air flow through the unit is regulated automatically by the hygrometer or manually.

The absorption capacity of the first cartridge and the volume of air flow through it were calculated to give it the capability of absorbing the /8 total moisture excreted by a cosmonaut in a state of rest under comfortable temperature conditions (40 to 50 g/hr), deducting the moisture absorbed by the regenerator.

Under these conditions the relative humidity in the cabin should not exceed 70%. In case the excretion of moisture by the human operator should increase due to increased air temperature in an emergency, or for any other reasons connected with emotional tension or increased physical activity,

*See fig. 1.

ambient humidity increased and the second, reserve drier was automatically activated. In the case of emergency increase in air temperature, when a considerable proportion of cooling was accomplished by evaporation of perspiration, the cosmonaut could open the manually operated valves and significantly increase air flow through the drier. This made it possible to maintain heat balance at elevated temperatures up to 35°C.

The ratio f air flow through the drying and regenerating cartridges, as well as the moisture capacity of all elements of the air regeneration system, was established assuming an optimum rate of consumption of the regenerating substance and the maintenance of the most favorable possible conditions for the cosmonaut in normal and emergency situations.

The unit for automatic maintenance of preset temperature conditions consisted of two circulation channels: an air circulation system, open to the space inside the pressurised cabin, and a closed liquid circulation system connected with a heat radiator located on the external surface of the vehicle.

The interface between the two systems consisted of a liquid-air heat exchanger inside the pressurized cabin. /9

The components of the temperature control system located inside the pressurized cabin included:

1) A liquid-air heat exchanger (10)*
2) A fan with electric motor (27)
3) automatic thermostatic control (11, 12, 13, 14, 15)

Designwise, the greater part of these components were combined into a single unit containing the fan, heat exchanger with condensation collector, and the thermostatic control.

*See fig. 1.

The automatic air temperature regulator consisted of a sensor and an effector mechanism which regulated the flow of air through the heat exchanger according to the temperature set by the cosmonaut on the control. Air temperature was maintained with an accuracy of ± 1.5°C.

The vehicle was also equipped with an emergency temperature control system based on the evaporation of liquid jettisoned into the void. This system was activated by an emergency cabin air temperature rise to 35°C.

The unit for monitoring the parameters of the pressurized cabin atmosphere consisted of:

1) An automatic O_2 and CO_2 gas analyzer (24, 25, 26)*
2) An ambient humidity hygrometer (16)
3) An ambient temperature thermometer (18)
4) An ambient air pressure barometer (17)

All these indices were reported by dials with pointers on the cosmonaut's instrument panel. /10

Observation of the operation of the air regeneration and air conditioning systems and monitoring of the gas composition of the cabin atmosphere during flight was provided for in the system by the inclusion of radiotelemetric monitoring of the basic parameters characterising the operation of system components and the composition of the artificial atmosphere.

All this information permitted timely analysis of air regeneration and air conditioning system operation and the choice of a correct decision, in case of need (in emergencies), for maintaining the required conditions.

From the beginning of the planning stage up until the completion of the first flight of a Vostok vehicle, the life support systems underwent a series of manned tests in pressure chambers and in Vostok mockups on the ground.

*See fig. 1.

These experiments investigated and tested mockups and trial models of systems. The length of the experiments was from 1 to 15 days. The trial conditions of some of the experiments closely approximated flight conditions.

After the series of laboratory trials and appropriate modifications, flight test models of the systems were also tested on orbital spacecraft with animals on board.

The sum of the experiments conducted made clear the characteristics of the system, its operating regime, and the possible nature of changes in atmosphere parameters as they depended on the duration and thermal conditions of the experiments.

Concurrent investigations were conducted on the problem of the condition of a man during a long sojourn in the closed volume of a pressurised cabin under conditions of an artificial atmosphere created by an air regeneration and air conditioning system. /11

The atmosphere conditions obtaining in the Vostok cabin mockup during these experiments were characterised by the following limit values of the basic parameters:

barometric pressure, 740 to 900 mm Hg
air temperature, 15° t.. ..
relative humidity, 32% to 75%
oxygen cont..., 21% to 33% (150 to 300 mm Hg)
carbon dioxide content, 0.3% to 1.0% (2 to 9 mm Hg)

This is illustrated in fig. 2, which shows variations in atmosphere parameters during a 13-day control experiment.

The experiments conducted indicated that a prolonged sojourn by a human being dressed in a suit in a Vostok cabin did not cause any essential changes

in physiological functions.

In all the experiments the condition of the subjects remained satisfactory. No essential changes were noted with respect to the cardiovascular and respiratory systems, even during deliberate elevation of the air temperature to 35°C. Body temperature of the subjects fluctuated between 36° and 37°C. During all the experiments the subjects reacted adequately to stimulation and performed the tasks set them by the experimentors accurately and on time.

On the basis of medical examinations, the state of health of the subjects following the experiments was concluded to be satisfactory.

After conclusion of a series of final tests, the life support sys- /12
tems were approved for use on the first manned spaceflight. In the course of flight the system functioned a total of about 5 hrs on the ground and in flight. During this time the parameters of the atmosphere in the pressurized cabin of the Vostok vehicle fluctuated between the following limits:

pressure, from 750 to 755 mm Hg

temperature, from + 19° to + 20°C

humidity, from 62% to 69%

O_2 concentration, from 21% to 22%

CO_2 concentration, from 0.4% to 0.6%

All system components functioned faultlessly.

The prolonged flight experiments subsequently performed with Vostok vehicles confirmed the above results. The system was used successfully on Vostok flights by Cosmonauts G. S. Titov, A. G. Nikolayev, P. R. Popovich, V. F. Bykovskiy, and V. V. Tereshkova.

In the course of all 5 flights the air regeneration and air conditioning systems performed flawlessly to maintain the required conditions in the cabins

of Vostok-2, Vostok-3, Vostok-4, Vostok-5, and Vostok-6.

Systems operation control was automated on all flights, and the cosmonauts had no occasion to resort to manual control except for temperature, which they regulated according to thermal comfort.

The longest of all the flights made was that of the spacecraft Vostok-5 with V. F. Bykovskiy.

Since the duration of trouble-free operation is the most important char- /13
acteristic for evaluating an air regeneration and air conditioning system, it is possible to limit our analysis to the performance of the system of Vostok-5 and illustrate it with the changes of cabin atmosphere parameters on that flight (fig. 3).

As shown in the figure, the oxygen concentration increased during the first two days of flight, reaching a value of 29% (226 mm Hg) by the end of the second day. For the entire remainder of the flight the oxygen concentration did not exceed this value and fluctuated between 28% and 29%.

The CO_2 concentration in the cabin atmosphere fluctuated between 0.24% and 0.57%. The humidity of the air varied during the flight from 42% to 56%.

The temperature inside the pressurized cabin was + 26°C at the beginning of the flight. During the first 24 hours it dropped to + 13°C and later stabilized between + 11° and + 14°C.

The nature of the changes in air temperature and oxygen concentration was basically determined by the total pressure of the atmosphere inside the cabin. This varied little (775 to 800 mm Hg).

Thus, in the course of the flight the parameters of the ambient medium in the pressurized cabin of the Vostok-5 vehicle were within the limit values for comfort. This had an extremely beneficial effect on studies of the effect

of weightlessness on the human body. All components of the system functioned perfectly.

In the course of the flights of the other Vostok vehicles, conditions in the pressurized cabins did not basically differ from the conditions described above.

The data of post-flight analysis of regenerative substance and /14 drier depletion made it possible to determine the average hourly gas metabolism of the cosmonauts and their moisture excretion. These data for each cosmonaut were as follows:

	O_2 consumption	CO_2 excretion	H_2O excretion	Respiration coefficient
1) Nikolayev, A. G.	17.6 liters/hr	15.0 liters/hr	40 g/hr	0.86
2) Popovich, P. R.	20.0 liters/hr	17.0 liters/hr	47 g/hr	0.85
3) Tereshkova, V. V.	17.3 liters/hr	14.1 liters/hr	23 g/hr	0.82
4) Bykovskiy, V. F.	17.5 liters/hr	14.5 liters/hr	33 g/hr	0.83

The results obtained on the operation of the Vostok air regeneration and air conditioning systems in both ground and flight experiments once more demonstrate the high quality and reliability of these systems in maintaining the required conditions in the cabins of space vehicles.

In the course of the flight of the three cosmonauts on the Voskhod vehicle, the air regeneration and air conditioning system functioned for a total of 28 hours, 4 of them at the start during preparation for flight. The vehicle cabin was sealed 1 hour before launch. Measurements conducted before the launch indicated normal functioning of the system in maintaining the required atmosphere parameters. After the cabin was sealed the internal air temperature was equal to + 17°C, relative humidity was 47%, partial oxygen pressure was 152 mm Hg, CO_2 concentration was less than 1%, and the pressure was 762 mm Hg.

During the flight all atmosphere parameters remained within the limits /15 of the prescribed norms. Thus, pressure varied between 762 and 800 mm Hg, temperature ranged from 17° to 22°C (the cosmonauts were dressed in sports clothes without spacesuits), ambient humidity fluctuated between 47% and 80%, partial oxygen pressure varied from 152 to 182 mm Hg, and the carbon dioxide concentration was about 1%.

Studies of the gas metabolism and moisture excretion of the cosmonauts made during flight on the basis of analysis of the regenerative substance and the dynamics of O_2, CO_2, and moisture concentration changes in the cabin air, show that specific spaceflight factors have no particular effect on energy expenditure, oxygen consumption rate, or carbon dioxide and moisture excretion rates. A slight tendency for basic metabolic indices to decrease deserves attention, and may be more pronounced on prolonged spaceflights.

The food ration devised for the Vostok and Voskhod vehicles is apparently quite satisfactory from the standpoint of calorie count and dietetic makeup. However, some intensification of protein metabolism, observed in the cosmonauts after flight, and also an increase in vitamin requirements, especially vitamin B_6, should be taken into account.

The characteristics of metabolism under spaceflight conditions requires further investigation, especially on flights of greater duration. The results of these investigations may provide corrective modifications to the food ration for cosmonauts which are essential to the support of deep-space voyages.

Figure 1. Main diagram of Vostok air regeneration and conditioning.

0	-	antidust and noxious substance filters
1	-	fan
2,3,4	-	regulated regenerators
5,6	-	drier
7,8	-	manual valves
9	-	automatic valve
10	-	liquid-air heat exchanger
11	-	radiator
12	-	actuating set-up (cover actuator)
13	-	amplifier
14	-	thermostatic control
15	-	temperature sensor
16	-	hygrometer
17	-	ambient air pressure barometer
18	-	temperature barometer
19	-	instrument panel
20-23	-	pressure, temperature, humidity s nsors
24-26	-	O_2 and CO_2 analyzer
27	-	Thermoregulator fan unit

Figure 2. Atmospheric parameter changes in prolonged experiment in Vostok mockup cabin.

P	-	atmospheric pressure (mm Hg)
T	-	atmospheric temperature (°C)
φ	-	relative atmospheric humidity
O_2	-	concentration (%)
CO_2	-	concentration (%)

Figure 3. Atmospheric parameter changes in Vostok-5 cabin with V.F. Bykovskiy.

P	-	atmospheric pressure (mm Hg)
T	-	atmospheric temperature (°C)
φ	-	relative atmospheric humidity
O_2	-	concentration (%)
CO_2	-	concentration (%)

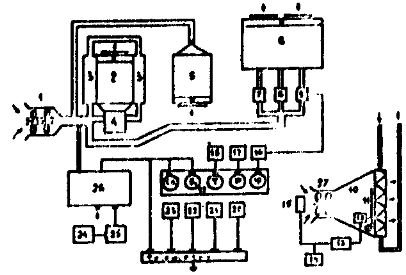

Figure I

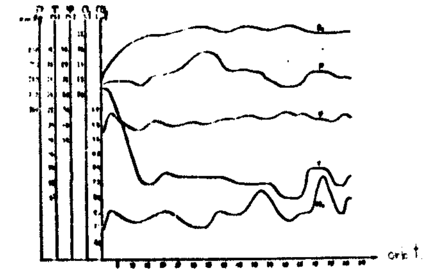

Figure II

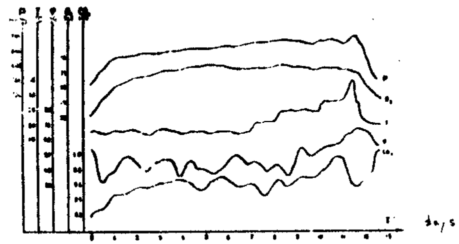

Figure III